Forum for Electromagnetic Research Methods and Application Technologies (FERMAT)

# Miniaturized Multi-mode Bandpass Filters Using Waveguide cavity

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**Sai Wai Wong**

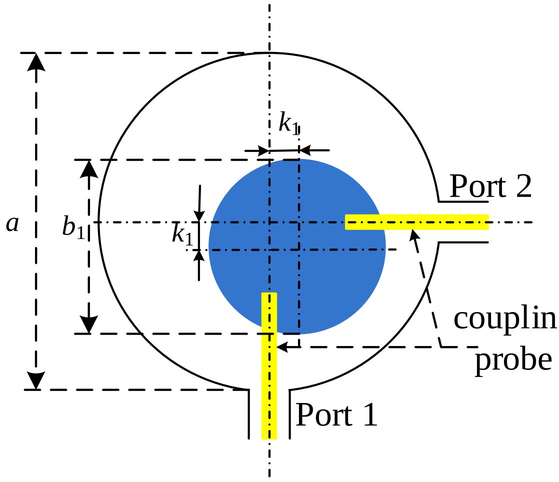
**Biography:** Sai-Wai Wong (S’06-M’09-SM'14) received the B.S degree in electronic engineering from the Hong Kong University of Science and Technology, Hong Kong, in 2003, and the M.Sc. and Ph.D. degrees in communication engineering from Nanyang Technological University, Singapore, in 2006 and 2009, respectively. From July 2003 to July 2005, he was an Electronic Engineer to lead the electronic engineering department in mainland of China with two Hong Kong manufacturing companies. From May 2009 to October 2010, he was a Research Fellow with the Institute for Infocomm Research, Singapore. From 2010 to 2014, he was an Associate Professor, and since 2014, a Professor in advance with the School of Electronic and Information Engineering, South China University of Technology, Guangzhou, China. His research interests include RF/microwave circuit and antenna design.Dr. Wong has authored and co-authored more than 80 international papers. He is holding 5 Chinese invention patents and 30 Chinese invention patents are pending. He is a reviewer for several top international journals in the field of microwave circuits. He was the guest editor for the “Special Issue on LTE Technology: Antenna, RF Front-Ends and Channel Modeling” of the International Journal of Antennas and Propagation. He was the recipient of the New Century Excellent Talents in University (NCET) awarded by Ministry of Education of China in 2013.

**Abstract**: This ppt presents the design and implementation of a class of multiple-mode wideband bandpass filter (MMRBPF). This BPF consists of a single waveguide cavity which is used to design triple-mode, quadruple-mode and quintuplet-mode wideband filter. This technology also extend to design a triple-mode dielectric filter and diplexer. The widest fractional bandwidth is equal to 360% at center frequency of 3.2 GHz, and the insertion loss is less than 0.5 dB in center frequency. The high performance BPF provides an alternative approach to develop a cavity-type of wideband filter for miniaturized base-station communication.

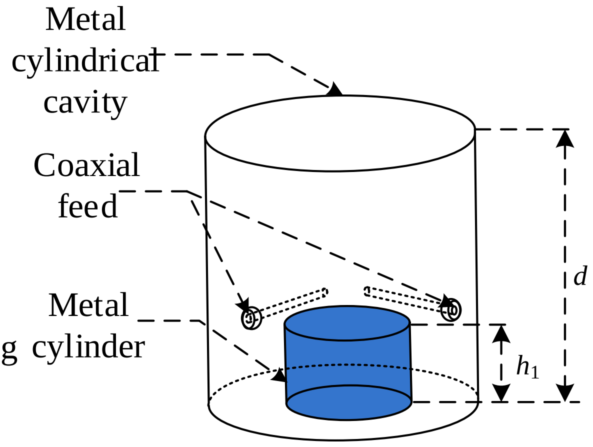
**key words:** Wideband Bandpass filter, Triple-mode, Cylindrical Waveguide, Miniaturization

# ➢ Filter and diplexer design

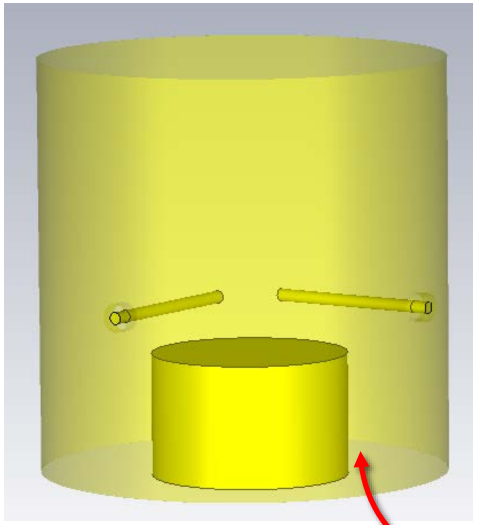
## a. Two types wideband multi-modes cavity filters—triple-mode


$k_1$
Port 2
$a$
$b_1$
$k_1$
coupling
probe
Port 1

Top view


Metal
cylindrical
cavity
Coaxial
feed
Metal
cylinder
$d$
$h_1$

Three-dimensional view



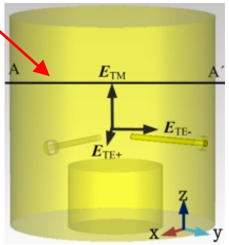
*Simulation modal in CST*

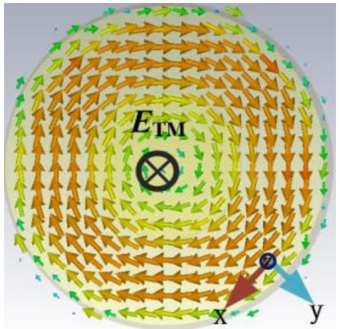
S. S. Wong, S. F. Feng, L. Zhu, and Q. X. Chu, “Triple- and quadruple-mode wideband bandpass filter using simple perturbation in single metal cavity,” *IEEE Trans. Microw. Theory Techn*., vol. 63, no. 10, pp. 3416–3424, Oct. 2015.

## ➢ Triple-mode

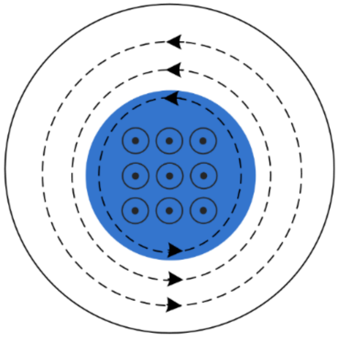
### Field distribution

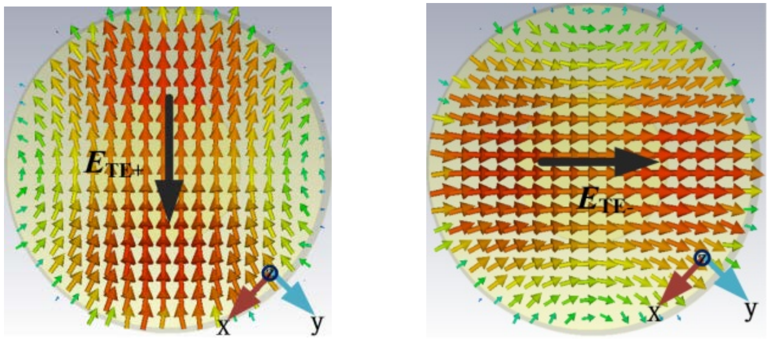
A-A’ plane for observing field distribution



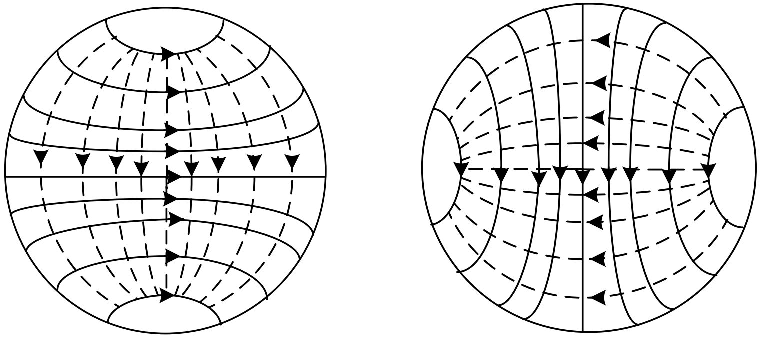


TM$_{01}$ mode B-field





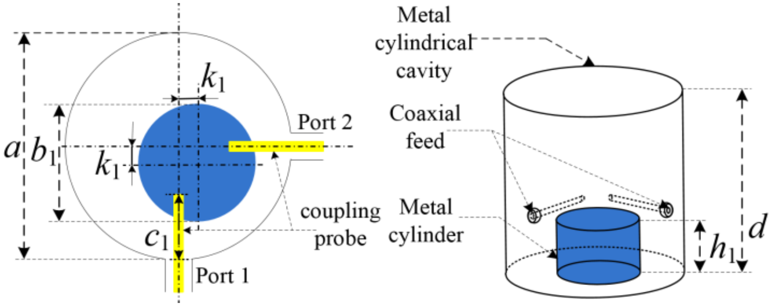
TE$_{11}$ mode E-field

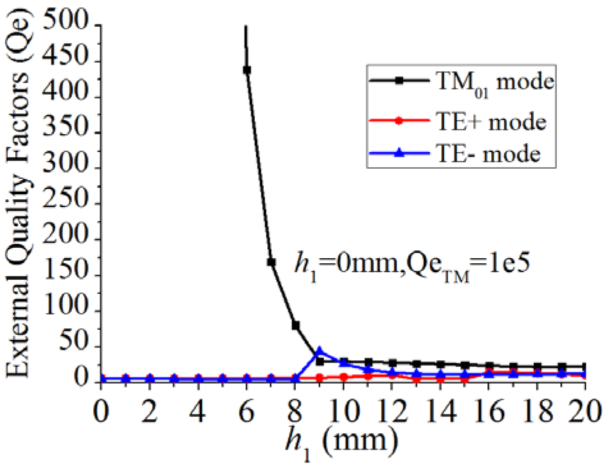


S. S. Wong, S. F. Feng, L. Zhu, and Q. X. Chu, “Triple- and quadruple-mode wideband bandpass filter using simple perturbation in single metal cavity,” *IEEE Trans. Microw. Theory Techn.*, vol. 63, no. 10, pp. 3416–3424, Oct. 2015.

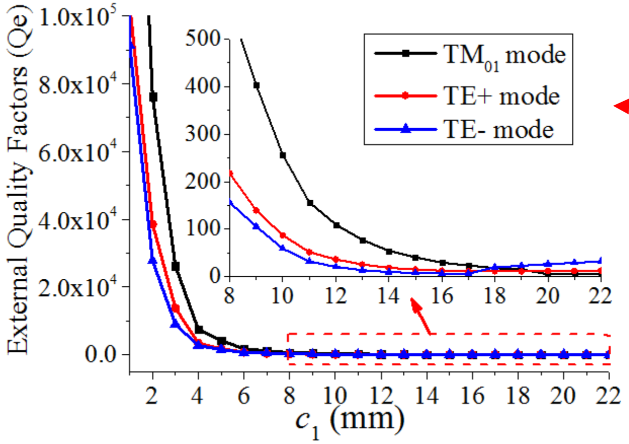
# ➢ Triple-mode

## External Q-factor


Metal cylindrical cavity
Coaxial feed
Metal cylinder
Port 2
Port 1
coupling probe
$a$
$b_1$
$k_1$
$k_1$
$c_1$
$h_1$
$d$



Height of cavity

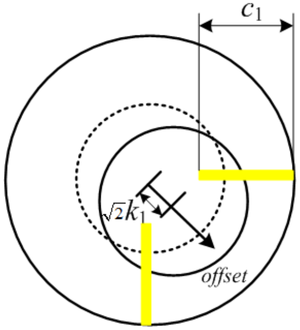


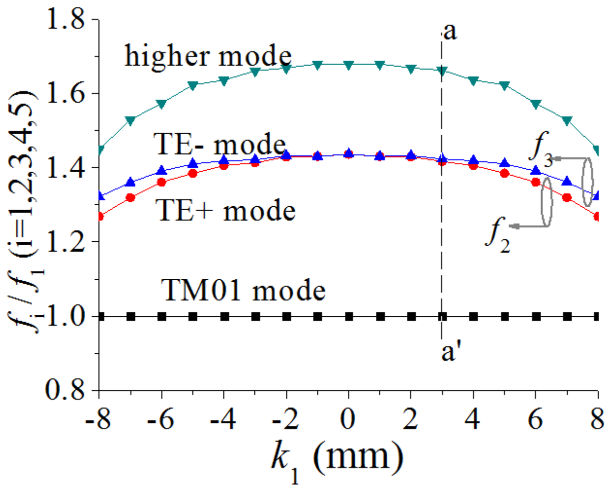
Length of coupling probes

S. S. Wong, S. F. Feng, L. Zhu, and Q. X. Chu, “Triple- and quadruple-mode wideband bandpass filter using simple perturbation in single metal cavity,” *IEEE Trans. Microw. Theory Techn.*, vol. 63, no. 10, pp. 3416–3424, Oct. 2015.

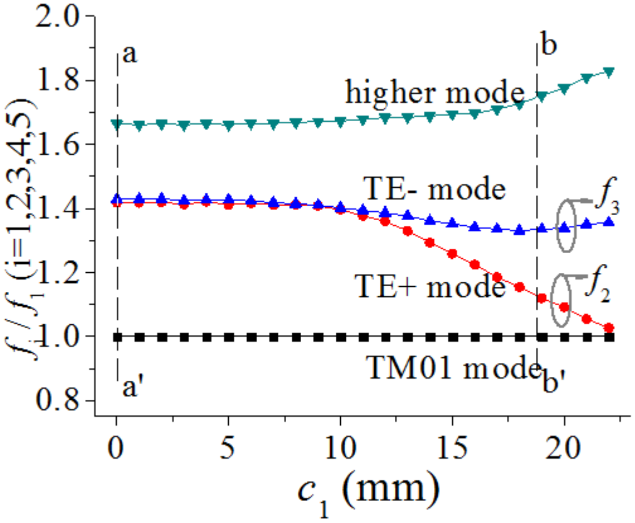
## Triple-mode

### Mode chart





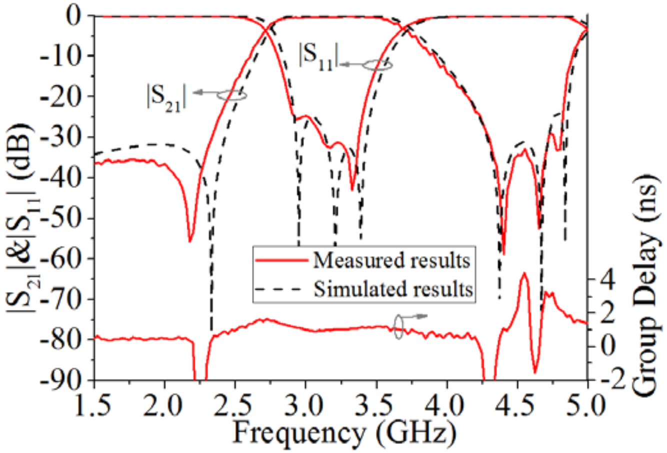
Change of the off-center distance $k_1$



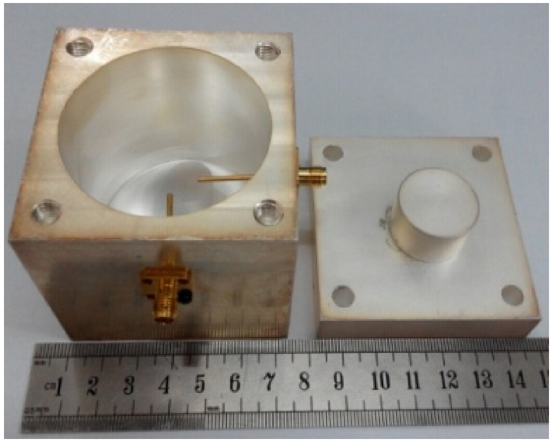
Change of the length of feeding probe $c_1$

S. S. Wong, S. F. Feng, L. Zhu, and Q. X. Chu, “Triple- and quadruple-mode wideband bandpass filter using simple perturbation in single metal cavity,” *IEEE Trans. Microw. Theory Techn.*, vol. 63, no. 10, pp. 3416–3424, Oct. 2015.

# ➢ Triple-mode



Fabricated triple-mode filter

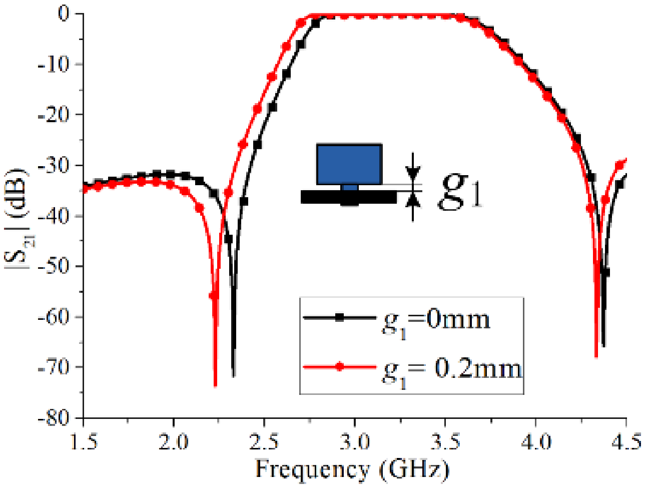


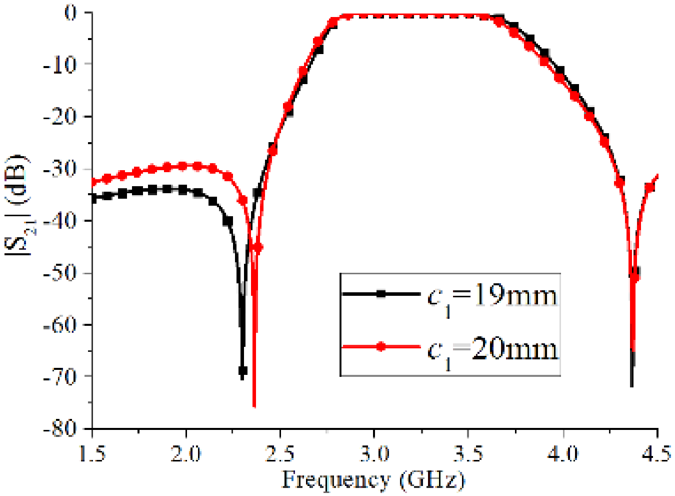
Measured and simulated results

S. S. Wong, S. F. Feng, L. Zhu, and Q. X. Chu, "Triple- and quadruple-mode wideband bandpass filter using simple perturbation in single metal cavity," *IEEE Trans. Microw. Theory Techn*., vol. 63, no. 10, pp. 3416–3424, Oct. 2015.

# ➢ Triple-mode

## Error analysis



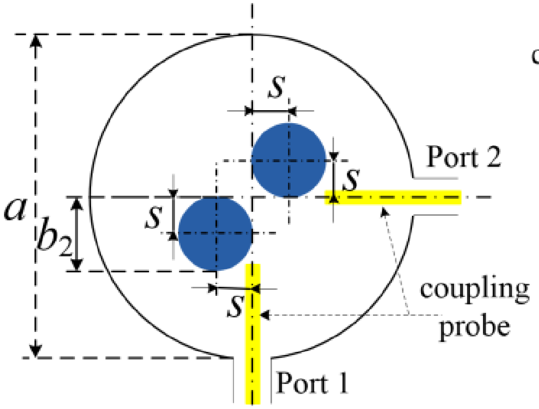


- The metal cylinder with perturbation generates a gap (parameter $g_1$) between the bottom of intra-cavity
- hand-soldered probes

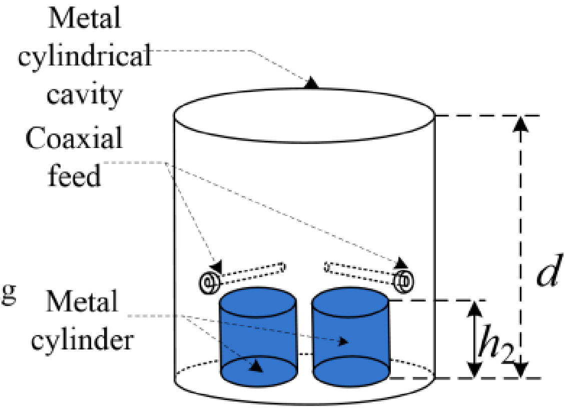
**S. S. Wong, S. F. Feng, L. Zhu, and Q. X. Chu, "Triple- and quadruple-mode wideband bandpass filter using simple perturbation in single metal cavity," *IEEE Trans. Microw. Theory Techn.*, vol. 63, no. 10, pp. 3416–3424, Oct. 2015.**

# ➢ Filter and diplexer design

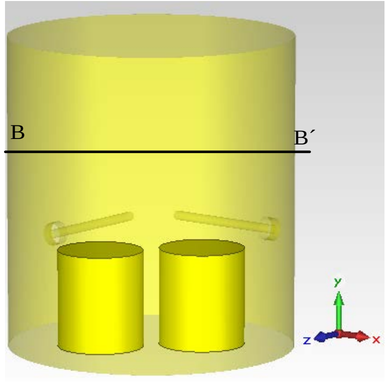
## a. Three types wideband multi-modes cavity filters—quadruple-mode


a
$b_2$
$s$
$s$
$s$
$s$
Port 2
coupling probe
Port 1

Top view


Metal cylindrical cavity
Coaxial feed
Metal cylinder
$d$
$h_2$

Three-dimensional view

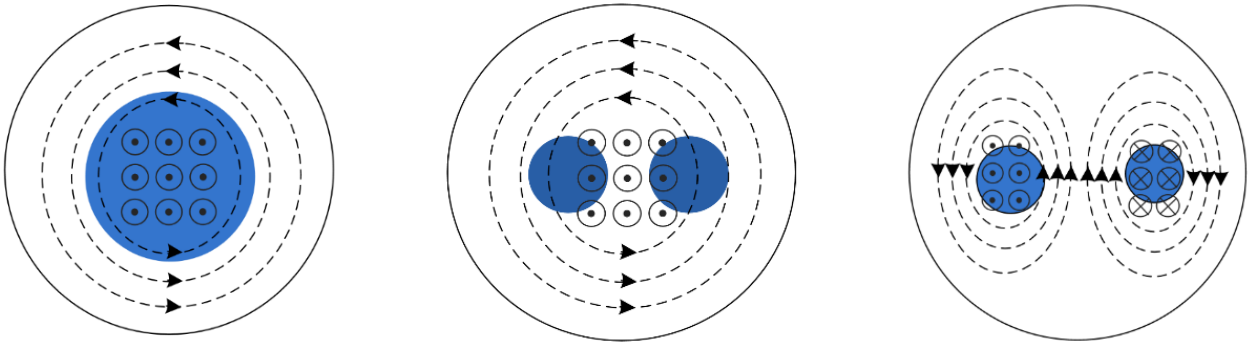


*Simulation modal in CST*

S. S. Wong, S. F. Feng, L. Zhu, and Q. X. Chu, “Triple- and quadruple-mode wideband bandpass filter using simple perturbation in single metal cavity,” *IEEE Trans. Microw. Theory Techn*., vol. 63, no. 10, pp. 3416–3424, Oct. 2015.

## Quadruple-mode

### Field distribution



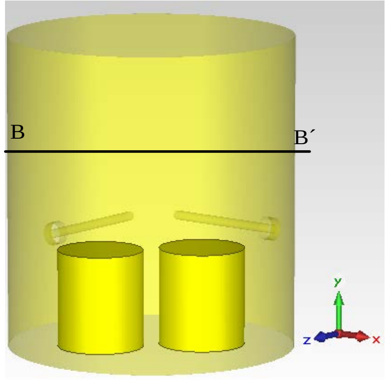
One perturbation rod→ Two perturbation rods

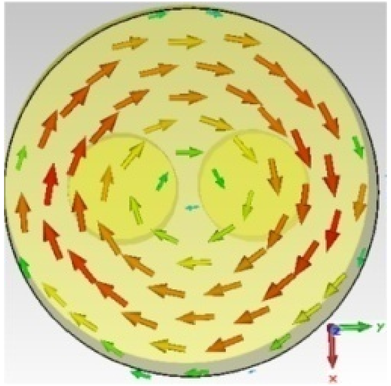
TM$_{01}$ mode → TM$_{01}$ mode、TM$_{11}$ mode

S. S. Wong, S. F. Feng, L. Zhu, and Q. X. Chu, “Triple- and quadruple-mode wideband bandpass filter using simple perturbation in single metal cavity,” *IEEE Trans. Microw. Theory Techn*., vol. 63, no. 10, pp. 3416–3424, Oct. 2015.

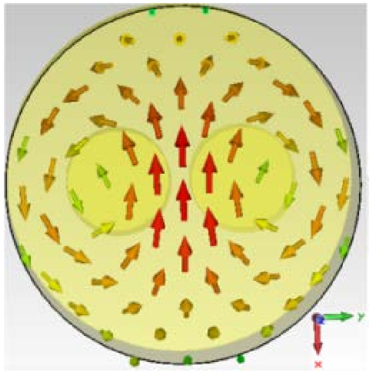
## Quadruple-mode

### Field distribution

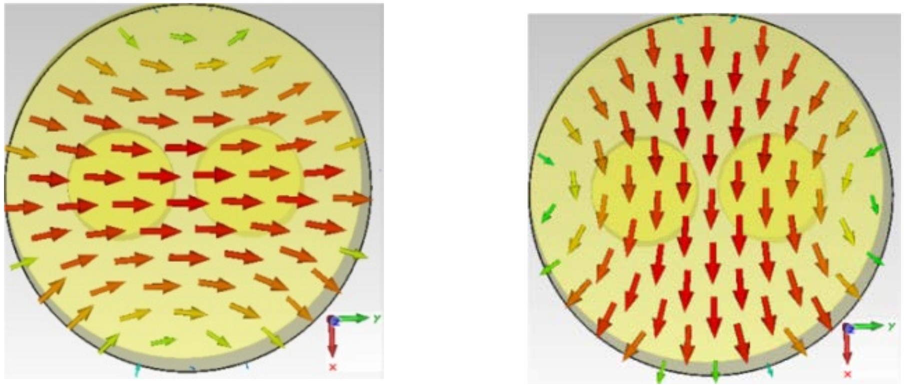




TM$_{01}$ mode B-field



TM$_{11}$ mode B-field

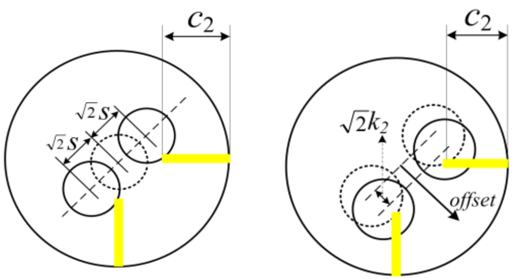


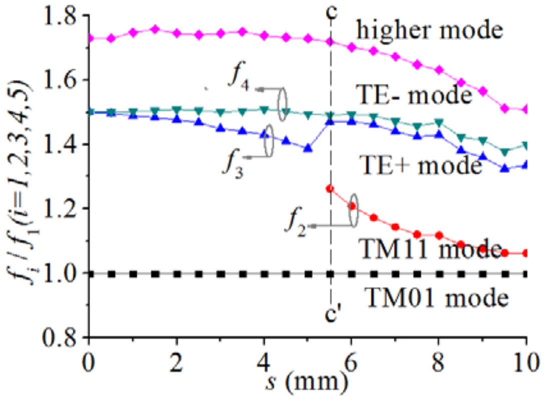
TE$_{11}$ mode E-field

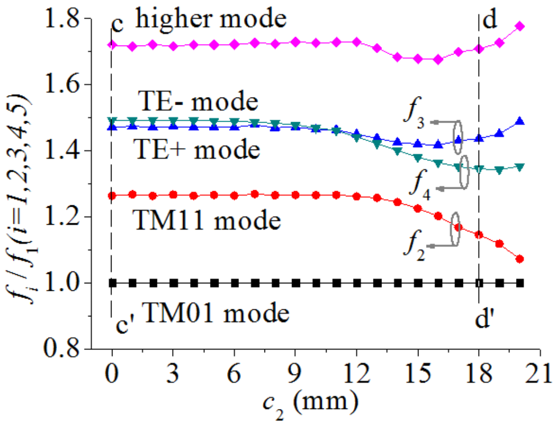
S. S. Wong, S. F. Feng, L. Zhu, and Q. X. Chu, “Triple- and quadruple-mode wideband bandpass filter using simple perturbation in single metal cavity,” *IEEE Trans. Microw. Theory Techn*., vol. 63, no. 10, pp. 3416–3424, Oct. 2015.

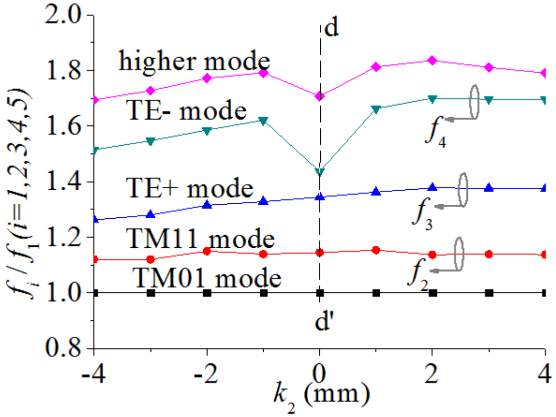
## ➢ Quadruple-mode

### Mode chart


$c_2$
$\sqrt{2}s$
$\sqrt{2}s$
$c_2$
$\sqrt{2}k_2$
offset



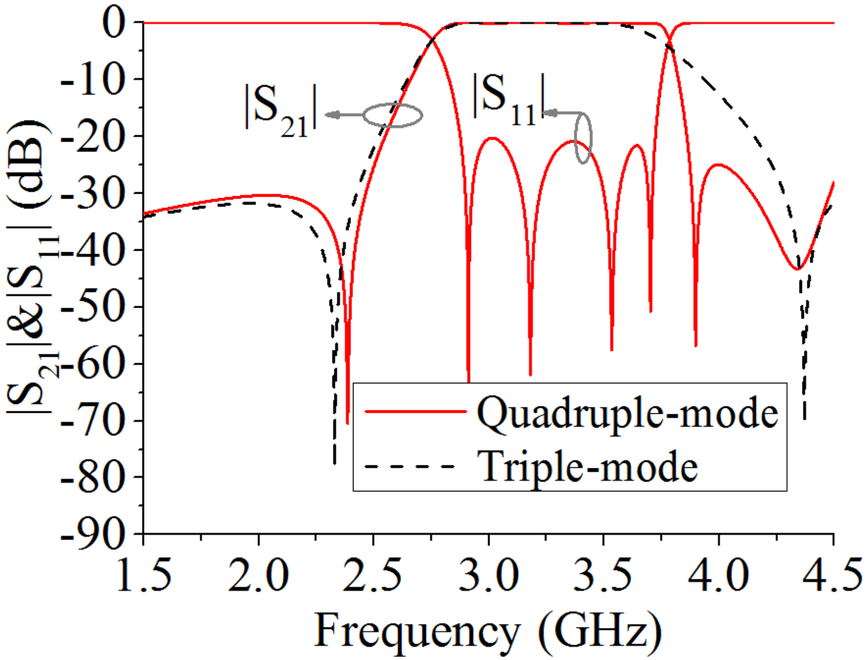




S. S. Wong, S. F. Feng, L. Zhu, and Q. X. Chu, “Triple- and quadruple-mode wideband bandpass filter using simple perturbation in single metal cavity,” *IEEE Trans. Microw. Theory Techn*., vol. 63, no. 10, pp. 3416–3424, Oct. 2015.

# ➢ Quadruple-mode

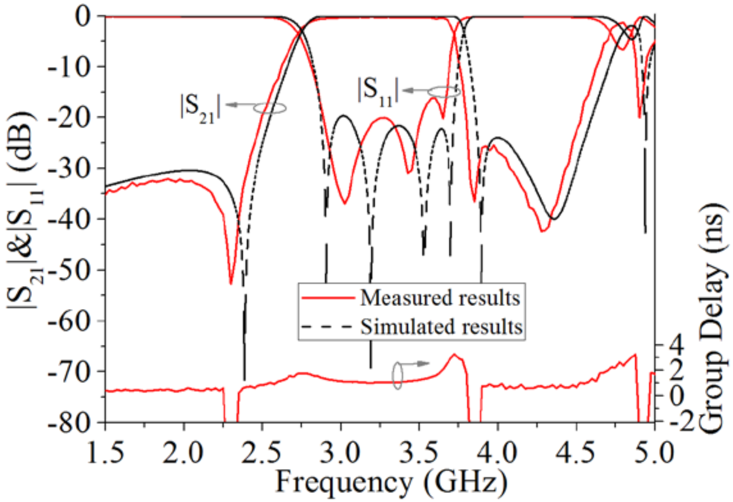
Comparison between triple-mode and quadruple-mode filter

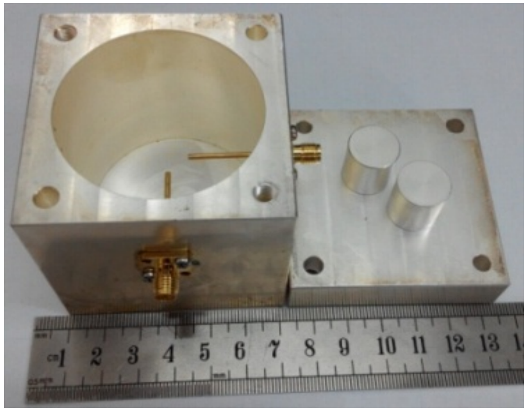


S. S. Wong, S. F. Feng, L. Zhu, and Q. X. Chu, “Triple- and quadruple-mode wideband bandpass filter using simple perturbation in single metal cavity,” *IEEE Trans. Microw. Theory Techn.*, vol. 63, no. 10, pp. 3416–3424, Oct. 2015.

# ➢ Quadruple-mode

Fabricated triple-mode filter



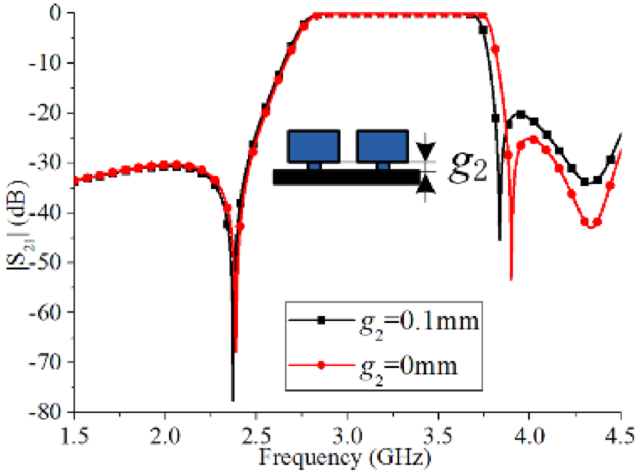


Measured and simulated results

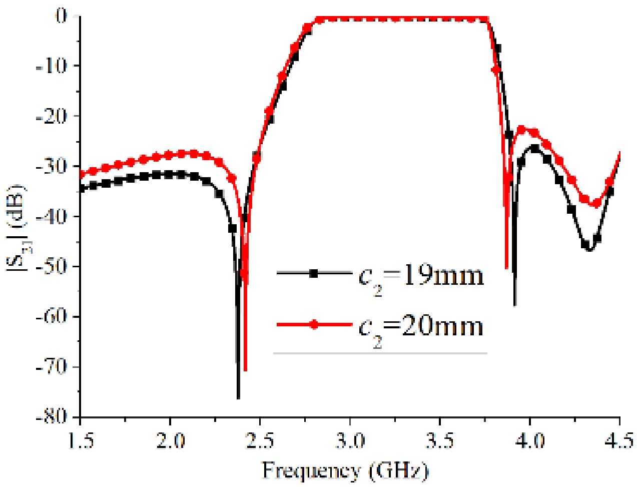
S. S. Wong, S. F. Feng, L. Zhu, and Q. X. Chu, “Triple- and quadruple-mode wideband bandpass filter using simple perturbation in single metal cavity,” *IEEE Trans. Microw. Theory Techn*., vol. 63, no. 10, pp. 3416–3424, Oct. 2015.

## ➢ Quadruple-mode

## Error analysis



Gap between perturbation cylinder and the bottom of the intra-cavity

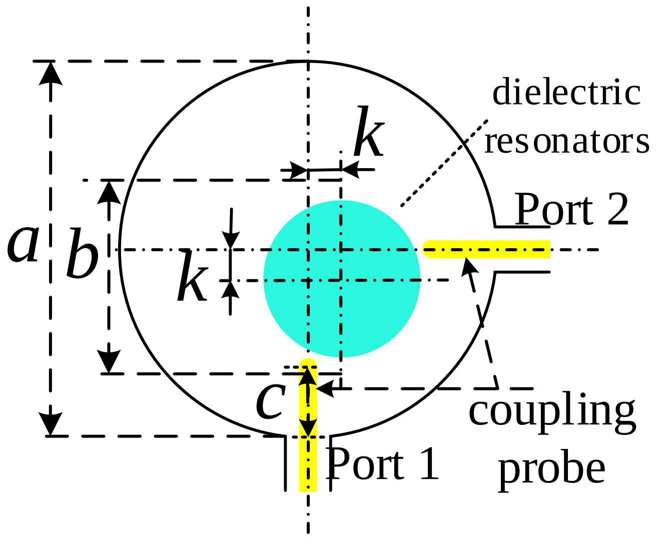


The effect of the length of two coupling probes.

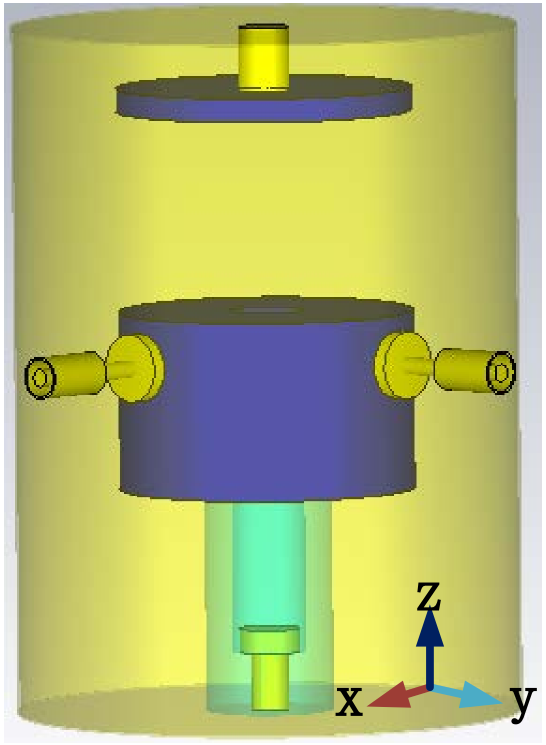
**S.W. Wong**, Z.C. Zhang, S.F. Feng, L. Zhu, F.C. Chen, and Q.X. Chu, "Triple-Mode Dielectric Resonator Diplexer for Base Station Applications" ***IEEE Transactions on Microwave Theory and Techniques***, vol. 63, no.12, pp. 3940-3953, Dec. 2015

# ➢ Filter and diplexer design

## b. Dielectric resonator triple-mode filter


dielectric
resonators
k
Port 2
a
b
k
c
Port 1
coupling
probe

Top view

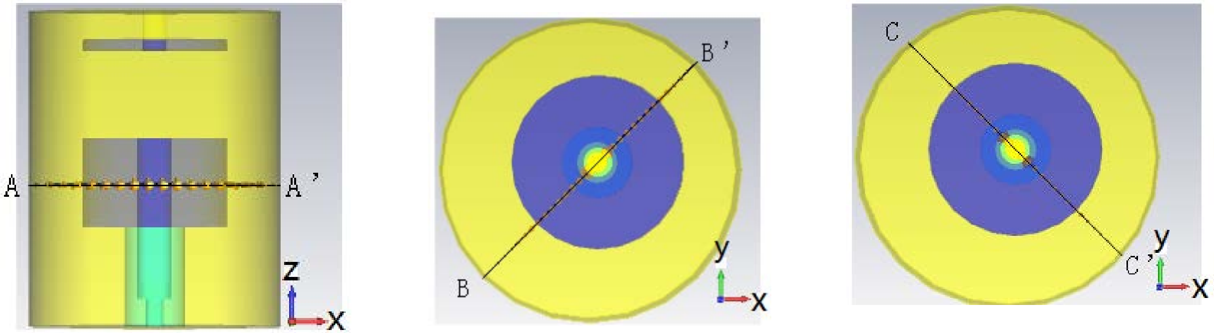


Three-dimensional view

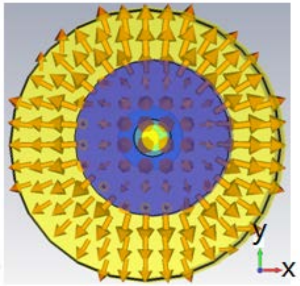
**S.W. Wong**, Z.C. Zhang, S.F. Feng, L. Zhu, F.C. Chen, and Q.X. Chu, "Triple-Mode Dielectric Resonator Diplexer for Base Station Applications" ***IEEE Transactions on Microwave Theory and Techniques***, vol. 63, no.12, pp. 3940-3953, Dec. 2015

## ➢ Dielectric resonator triple-mode filter

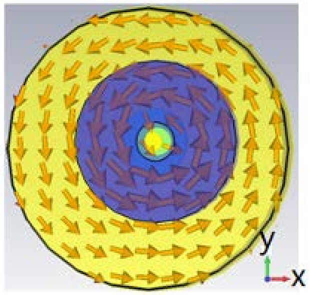
### Field distribution



TM mode



E-field



B-field

**S.W. Wong**, Z.C. Zhang, S.F. Feng, L. Zhu, F.C. Chen, and Q.X. Chu, "Triple-Mode Dielectric Resonator Diplexer for Base Station Applications" ***IEEE Transactions on Microwave Theory and Techniques***, vol. 63, no.12, pp. 3940-3953, Dec. 2015

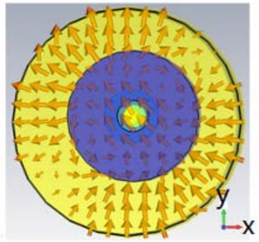
# ➢ Dielectric resonator triple-mode filter

## Field distribution

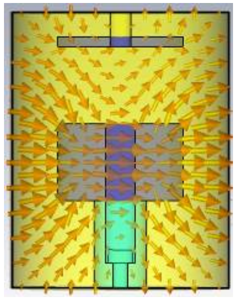
HE+ mode

HE- mode

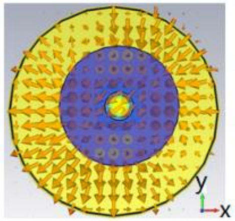
E-field



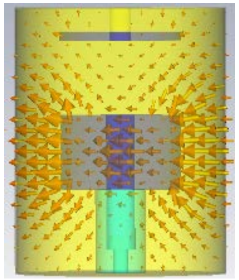
A-A' plane



B-B' plane

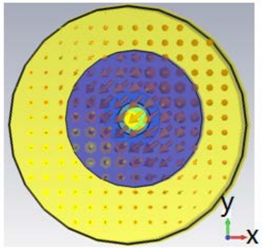


A-A' plane

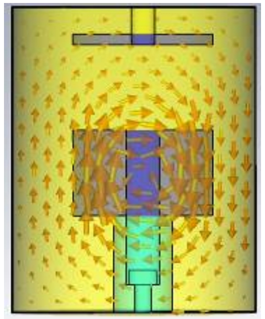


C-C' plane

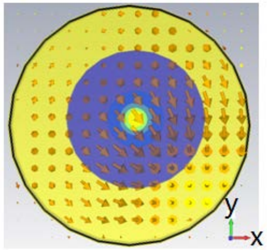
B-field



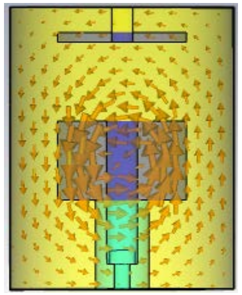
A-A' plane



C-C' plane



A-A' plane



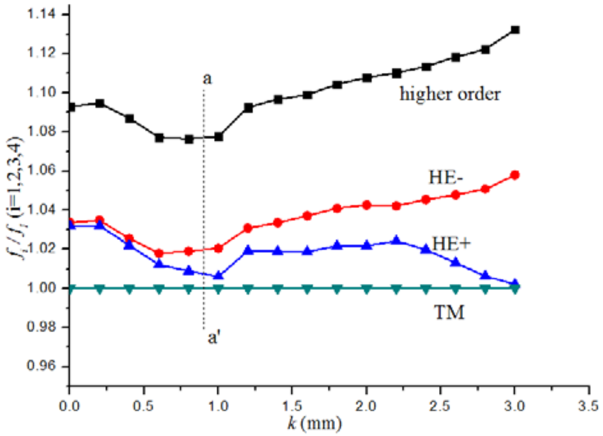
B-B' plane

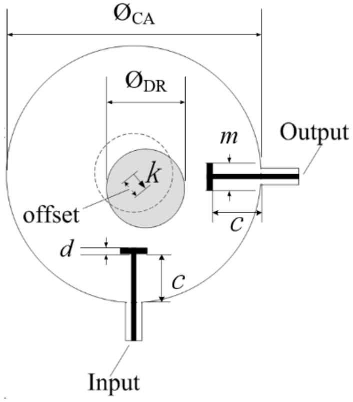
B-B' plane and C-C' plane are orthogonal to each other

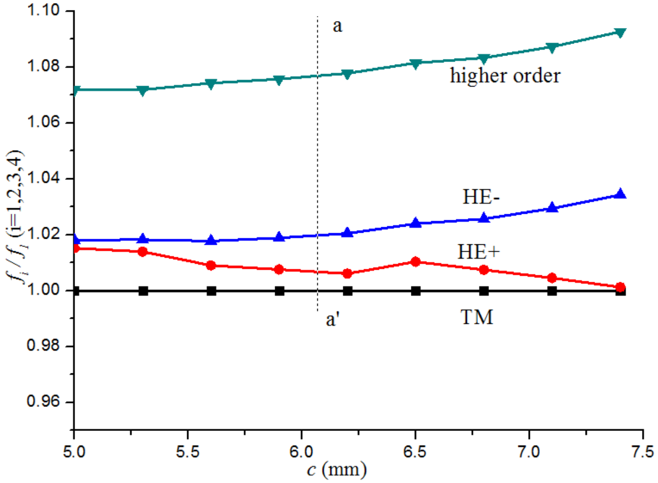
**S.W. Wong**, Z.C. Zhang, S.F. Feng, L. Zhu, F.C. Chen, and Q.X. Chu, "Triple-Mode Dielectric Resonator Diplexer for Base Station Applications" ***IEEE Transactions on Microwave Theory and Techniques***, vol. 63, no.12, pp. 3940-3953, Dec. 2015

## ➢ Dielectric resonator triple-mode filter

### Mode chart



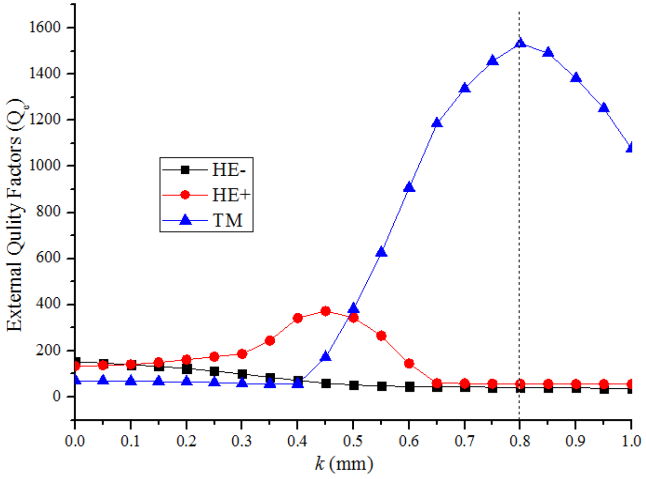

$Ø_{CA}$
$Ø_{DR}$
$m$
Output
$k$
offset
$c$
$d$
$c$
Input

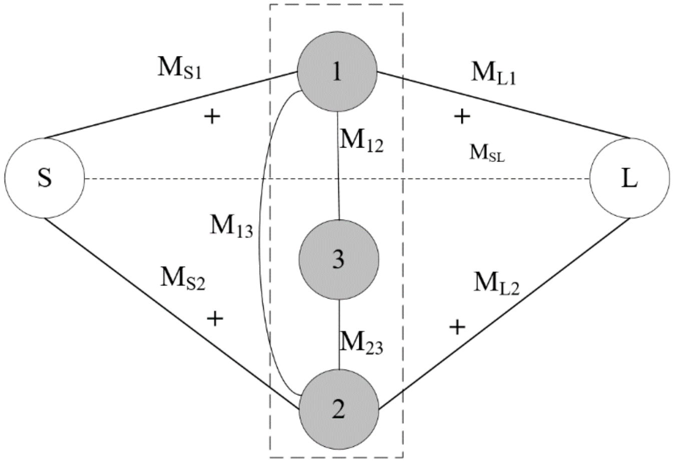


**S.W. Wong**, Z.C. Zhang, S.F. Feng, L. Zhu, F.C. Chen, and Q.X. Chu, "Triple-Mode Dielectric Resonator Diplexer for Base Station Applications" ***IEEE Transactions on Microwave Theory and Techniques***, vol. 63, no.12, pp. 3940-3953, Dec. 2015

# ➢ Dielectric resonator triple-mode filter

## External Q-factor



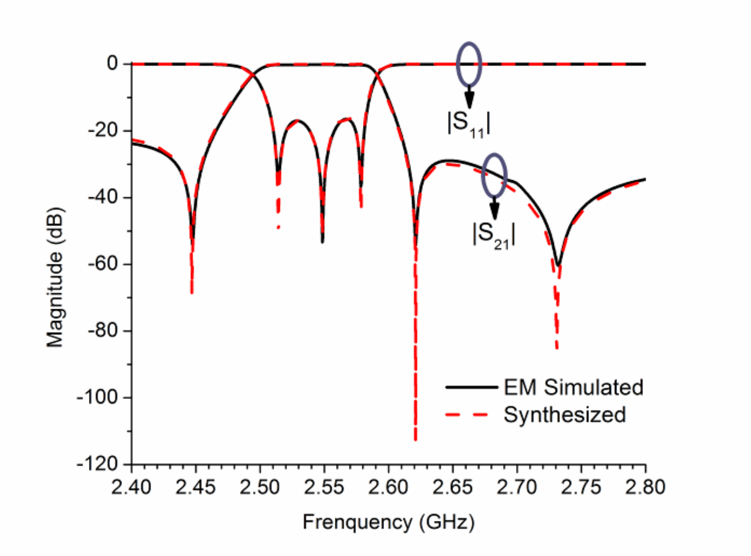

$M_{S1}$
$M_{L1}$
1
+
+
$M_{12}$
$M_{SL}$
S
L
$M_{13}$
3
$M_{S2}$
$M_{L2}$
+
+
$M_{23}$
2

**S.W. Wong**, Z.C. Zhang, S.F. Feng, L. Zhu, F.C. Chen, and Q.X. Chu, "Triple-Mode Dielectric Resonator Diplexer for Base Station Applications" ***IEEE Transactions on Microwave Theory and Techniques***, vol. 63, no.12, pp. 3940-3953, Dec. 2015

# Dielectric resonator triple-mode filter

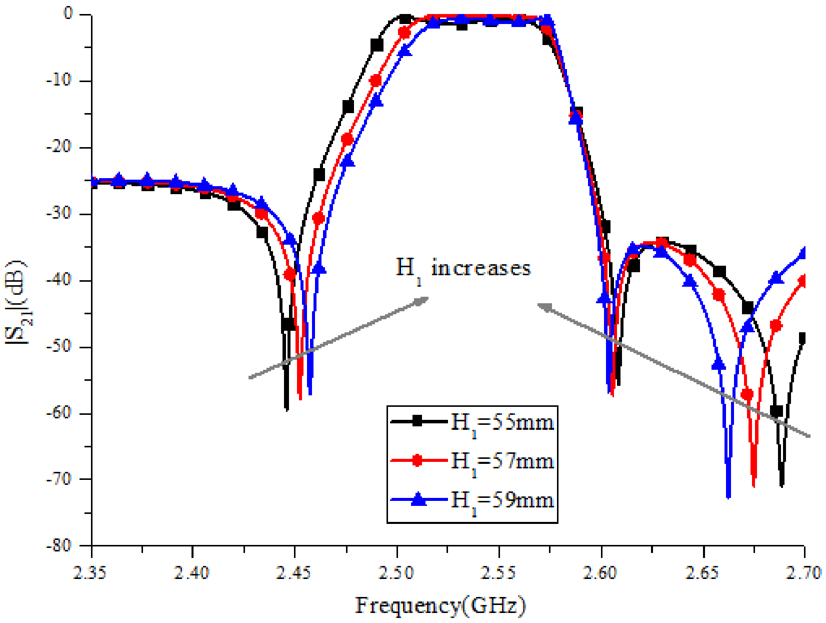
## Coupling matrix

$$M=\begin{bmatrix} 0 & 0 & 0.9366 & 0.3048 & -0.0330 \\ 0 & -0.2665 & 1.0917 & -0.6591 & 0 \\ 0.9366 & 1.0917 & 0.2305 & -0.2675 & 0.1666 \\ 0.3048 & -0.6591 & -0.2675 & -0.0490 & -0.9707 \\ -0.0330 & 0 & 0.1666 & -0.9707 & 0 \end{bmatrix}$$



**S.W. Wong**, Z.C. Zhang, S.F. Feng, L. Zhu, F.C. Chen, and Q.X. Chu, "Triple-Mode Dielectric Resonator Diplexer for Base Station Applications" ***IEEE Transactions on Microwave Theory and Techniques***, vol. 63, no.12, pp. 3940-3953, Dec. 2015

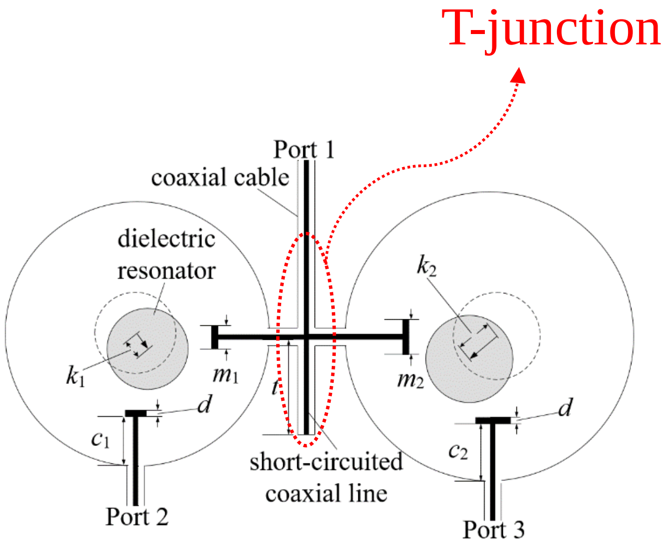
# ➢ Dielectric resonator triple-mode filter



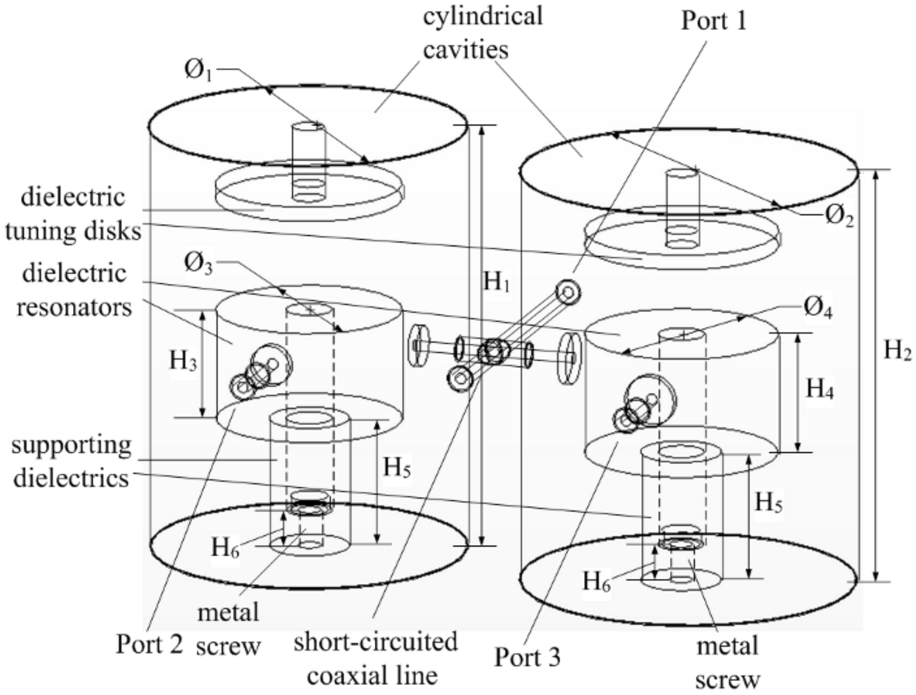
**S.W. Wong**, Z.C. Zhang, S.F. Feng, L. Zhu, F.C. Chen, and Q.X. Chu, "Triple-Mode Dielectric Resonator Diplexer for Base Station Applications" ***IEEE Transactions on Microwave Theory and Techniques***, vol. 63, no.12, pp. 3940-3953, Dec. 2015

# ➤ Filter and diplexer design

## b. Dielectric resonator triple-mode diplexer


T-junction
Port 1
coaxial cable
dielectric resonator
$k_1$
$m_1$
$t$
$m_2$
$k_2$
$d$
$c_1$
$c_2$
$d$
Port 2
short-circuited coaxial line
Port 3

Top view

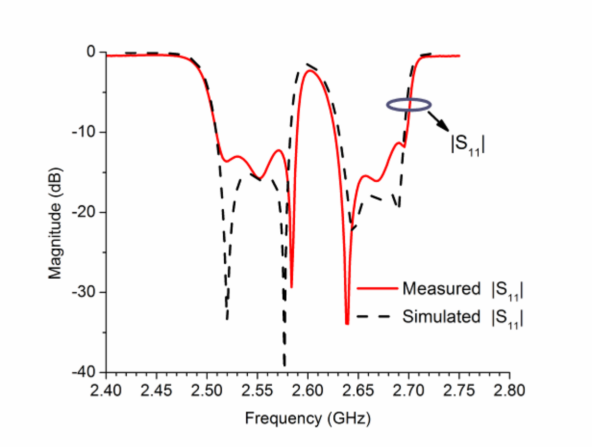

cylindrical cavities
Port 1
$Ø_1$
$Ø_2$
dielectric tuning disks
$Ø_3$
dielectric resonators
$H_1$
$Ø_4$
$H_2$
$H_3$
$H_4$
supporting dielectrics
$H_5$
$H_5$
$H_6$
$H_6$
metal screw
Port 2
short-circuited coaxial line
Port 3
metal screw

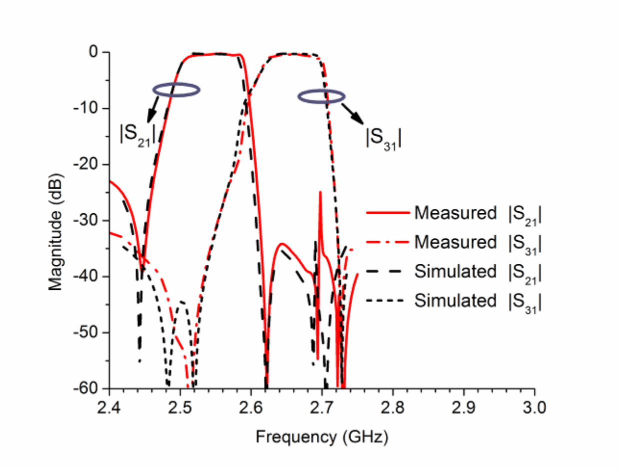
Three-dimensional view

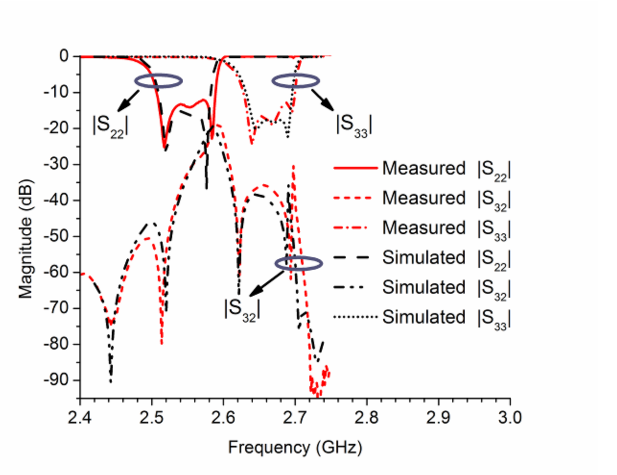
**S.W. Wong**, Z.C. Zhang, S.F. Feng, L. Zhu, F.C. Chen, and Q.X. Chu, "Triple-Mode Dielectric Resonator Diplexer for Base Station Applications" ***IEEE Transactions on Microwave Theory and Techniques***, vol. 63, no.12, pp. 3940-3953, Dec. 2015

# ➢ Dielectric resonator triple-mode diplexer

## S-parameter



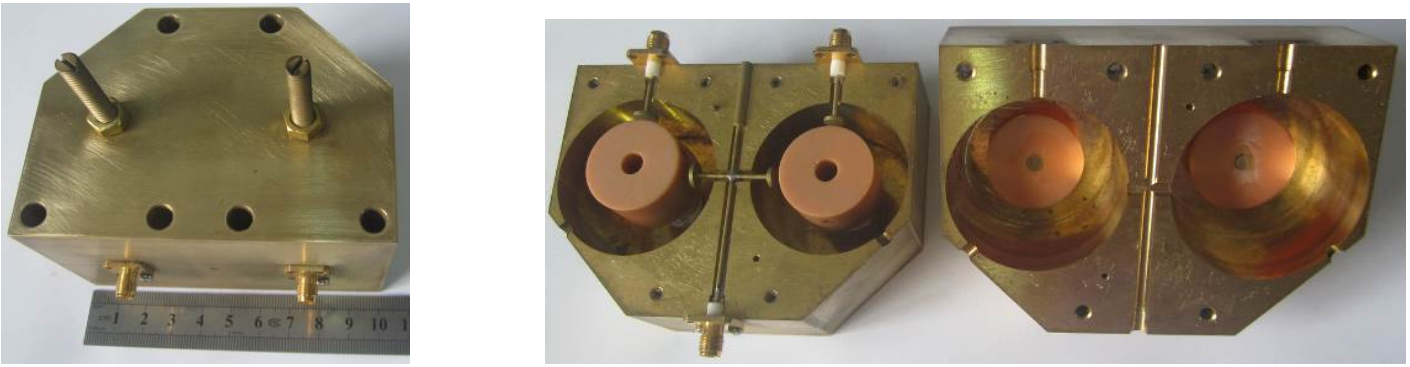




**S.W. Wong**, Z.C. Zhang, S.F. Feng, L. Zhu, F.C. Chen, and Q.X. Chu, "Triple-Mode Dielectric Resonator Diplexer for Base Station Applications" ***IEEE Transactions on Microwave Theory and Techniques***, vol. 63, no.12, pp. 3940-3953, Dec. 2015

## ➢ Dielectric resonator triple-mode diplexer

### Fabricated diplexer

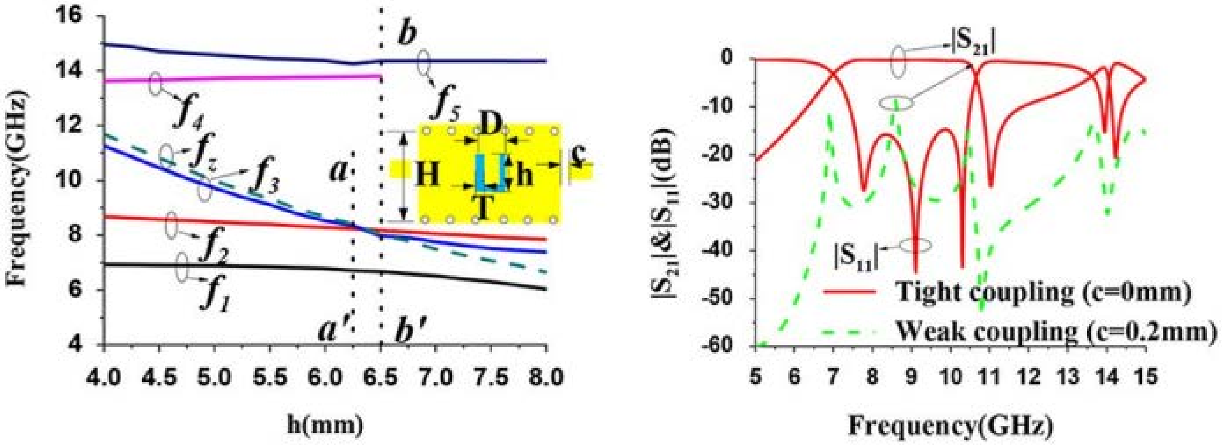


**S.W. Wong**, Z.C. Zhang, S.F. Feng, L. Zhu, F.C. Chen, and Q.X. Chu, "Triple-Mode Dielectric Resonator Diplexer for Base Station Applications" ***IEEE Transactions on Microwave Theory and Techniques***, vol. 63, no.12, pp. 3940-3953, Dec. 2015

# ➢ Filter and diplexer design

## c. U-slot SIW wideband filter

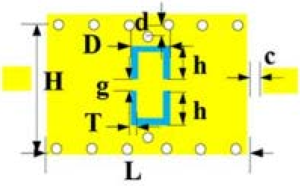
Single U-slot

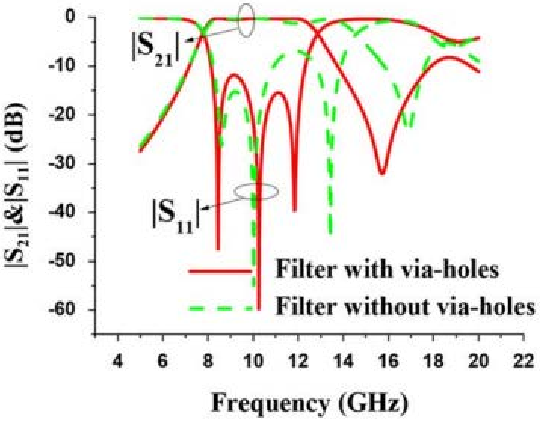


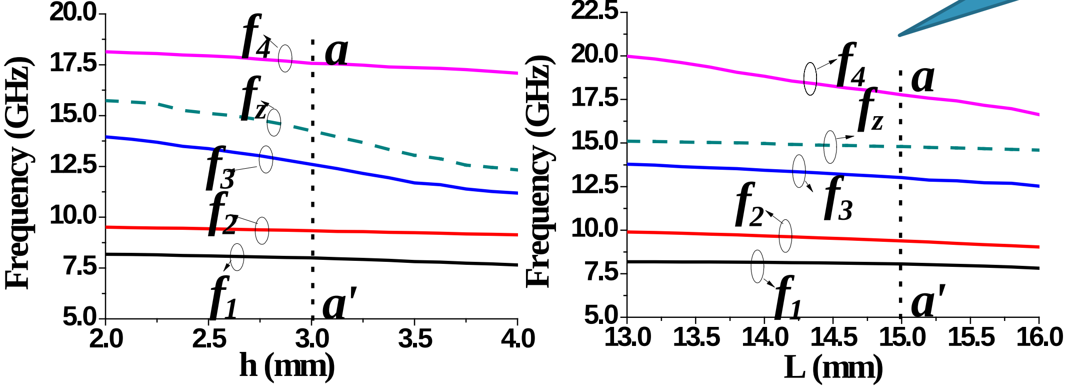
R. S. Chen, S. S. Wong, L. Zhu, and Q. X. Chu, “Wideband Bandpass Filter Using U-Slotted Substrate Integrated Waveguide (SIW) Cavities *IEEE Microw. Wireless Compon. Lett.*, vol. 25, no. 1, pp. 1–3, Jan. 2015.

## ➢ U-slot SIW wideband filter

Two U-slot





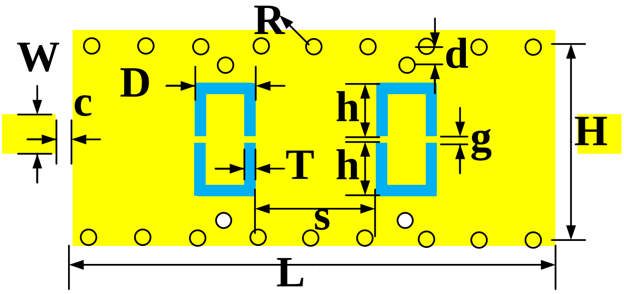


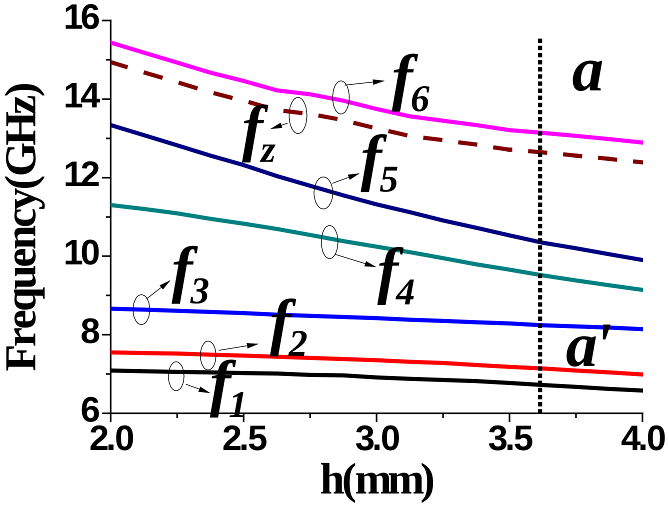
Mode chart

R. S. Chen, S. S. Wong, L. Zhu, and Q. X. Chu, “Wideband Bandpass Filter Using U-Slotted Substrate Integrated Waveguide (SIW) Cavities *IEEE Microw. Wireless Compon. Lett.*, vol. 25, no. 1, pp. 1–3, Jan. 2015.

# ➢ U-slot SIW wideband filter

## 5-pole filter

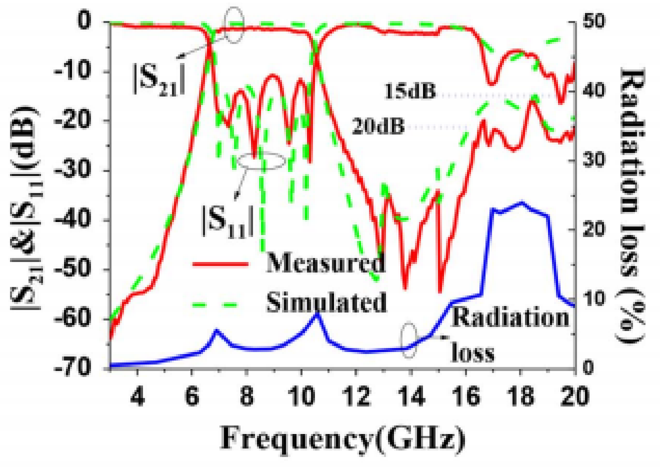


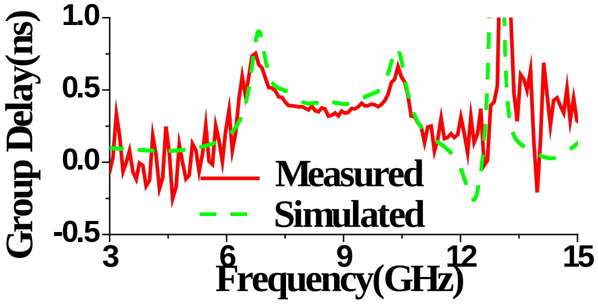


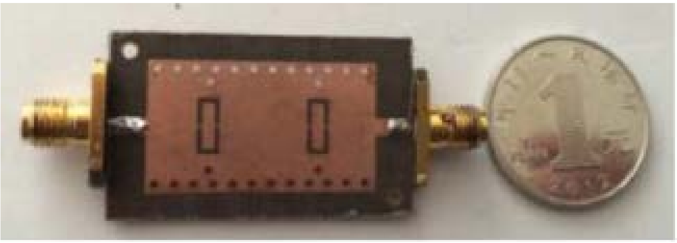
R. S. Chen, S. S. Wong, L. Zhu, and Q. X. Chu, "Wideband Bandpass Filter Using U-Slotted Substrate Integrated Waveguide (SIW) Cavities *IEEE Microw. Wireless Compon. Lett.*, vol. 25, no. 1, pp. 1–3, Jan. 2015.

# U-slot SIW wideband filter

## Measured and simulated results





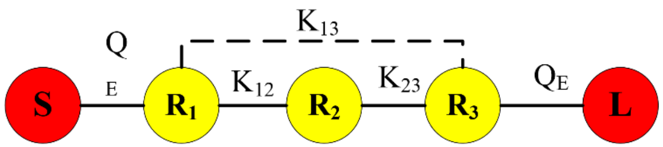


Fabricated triple-mode filter

R. S. Chen, S. S. Wong, L. Zhu, and Q. X. Chu, “Wideband Bandpass Filter Using U-Slotted Substrate Integrated Waveguide (SIW) Cavities *IEEE Microw. Wireless Compon. Lett.*, vol. 25, no. 1, pp. 1–3, Jan. 2015.

# ➢ Cross-Coupling on Microstrip Line for SIW BPF

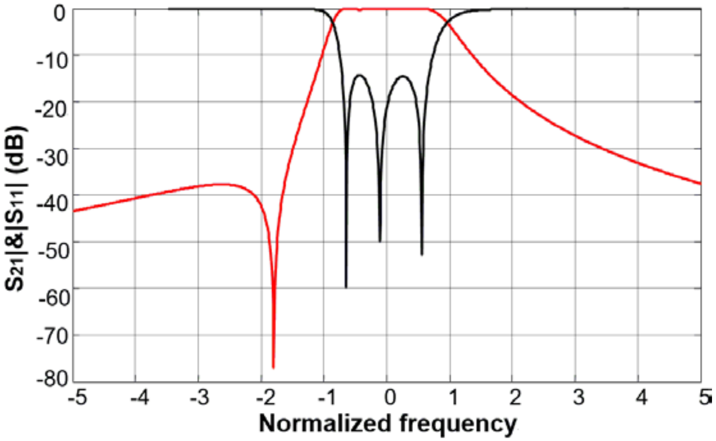
## Synthesis Method



Schematic of the proposed quasi-elliptic bandpass filters.

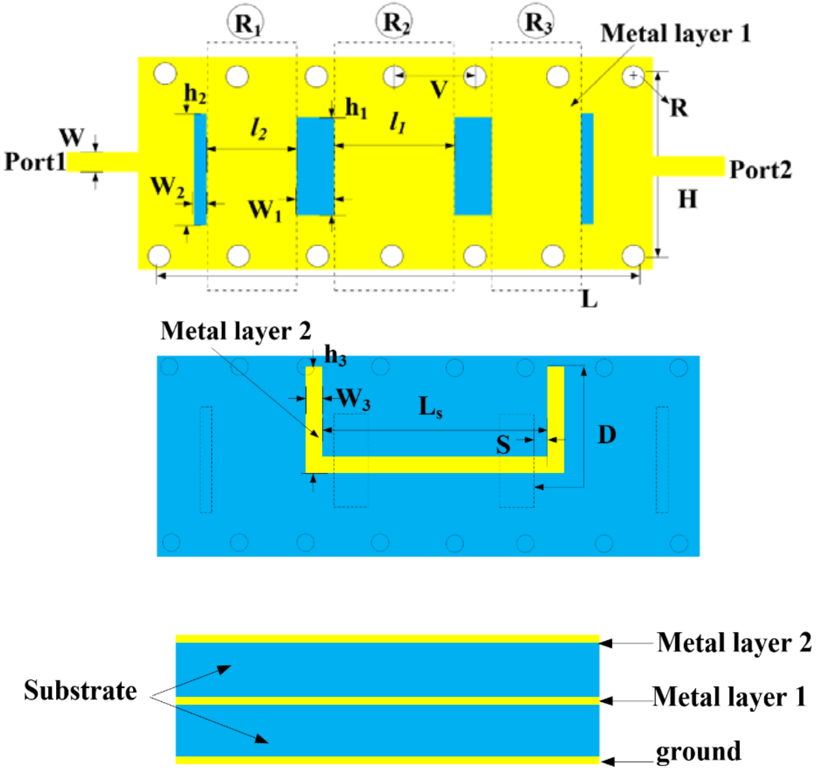
$$M = \begin{bmatrix} 0 & 0.7728 & 0 & 0 & 0 \\ 0.7728 & -0.0301 & 0.5691 & -0.2091 & 0 \\ 0 & 0.5691 & 0.2485 & 0.5691 & 0 \\ 0 & -0.2091 & 0.5691 & -0.0301 & 0.7728 \\ 0 & 0 & 0 & 0.7728 & 0 \end{bmatrix}$$

Normalized coupling matrices



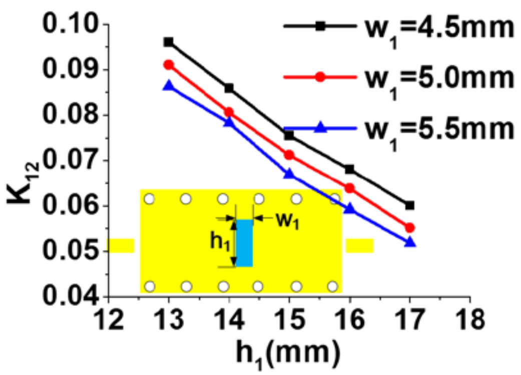
# ➢ Cross-Coupling on Microstrip Line for SIW BPF

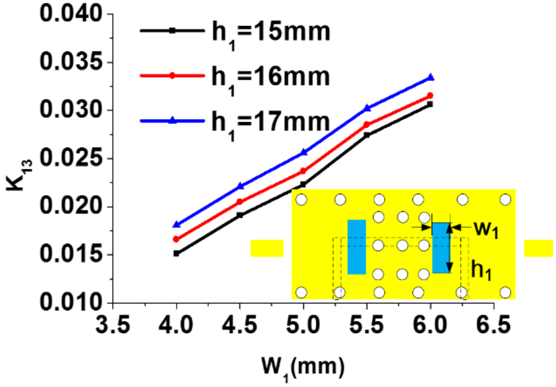
### Structure of proposed filter

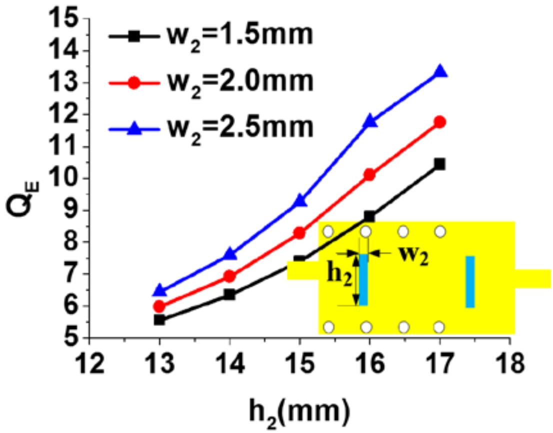

$R_1$
$R_2$
$R_3$
Metal layer 1
$h_2$
$h_1$
$l_2$
$l_1$
V
R
W
Port1
$W_2$
$W_1$
Port2
H
L
Metal layer 2
$h_3$
$W_3$
$L_s$
S
D
Substrate
Metal layer 2
Metal layer 1
ground

# ➢ Cross-Coupling on Microstrip Line for SIW BPF

## Parameter of structure



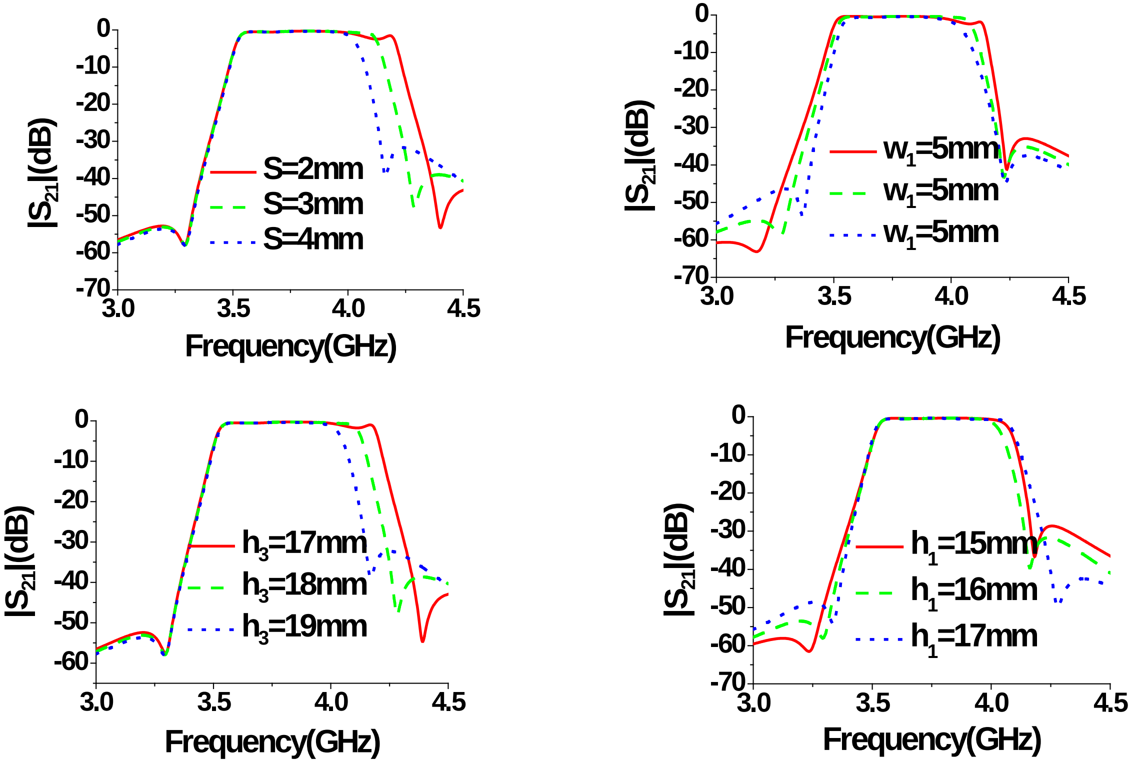




The final parameters of proposed filter are:w=2.2, $l_1$=25, $w_1$=5.4, $l_2$=18.8, $w_2$=1.5, Ls=44.2, $w_3$=2, L=97.5, $h_1$=16.1, H=28, $h_2$=15.5,R=0.5, $h_3$=18.5, V=2.5, s=4.2 (all in mm)

# ➢ Cross-Coupling on Microstrip Line for SIW BPF

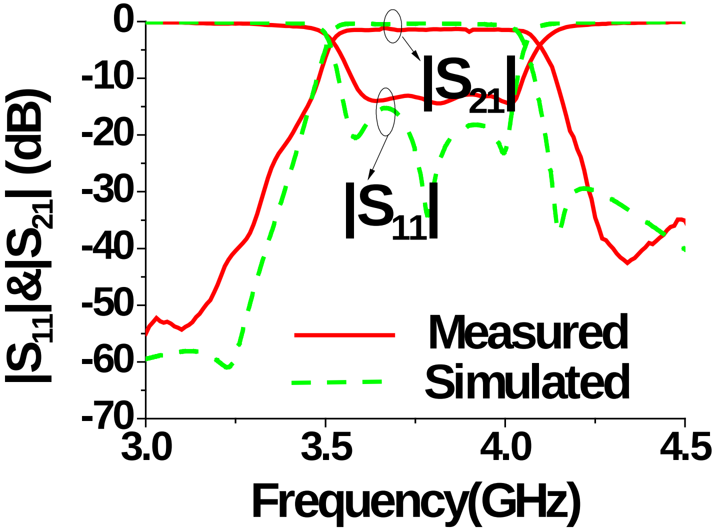
## Analysis transmission zeros of proposed filter

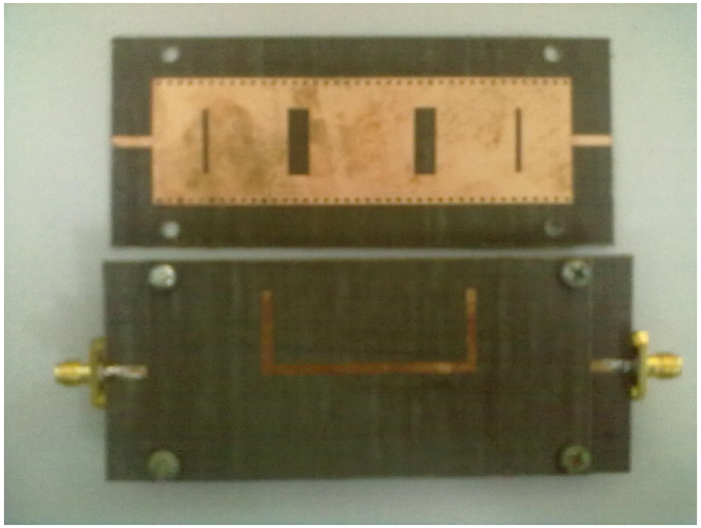


we found that an extra TZ appearing in the upper-stopband, we named the two TZs as $f_{z1}$ and $f_{z2}$. $f_{z1}$ is produced by the cross-coupling, $f_{z2}$ is produced by the open-ended stubs.

# ➢ Cross-Coupling on Microstrip Line for SIW BPF

## Experimental Results





Thank you !